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(71) Applicant (for all designated States except US): **RENISHAW PLC** [GB/GB]; New Mills, Wotton-under-Edge, Gloucestershire GL12 8JR (GB).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **STIMPSON, Victor, Gordon** [GB/GB]; Field House, Tetbury Hill, Avening, Gloucestershire GL8 8TL (GB). **FUGE, Jon**,

Paul [GB/GB]; 5 College View, Bath Road, Stonehouse, Gloucestershire GL10 2JR (GB). **DAVIES, William, Kenneth** [GB/GB]; 10 Squires Leaze, Thornbury, Bristol, South Gloucestershire BS35 1TB (GB). **LEETE, Norman, John** [GB/GB]; 4 Court Garden, Uley, Gloucestershire GL11 5AH (GB). **BELL, Colin, Timothy** [GB/GB]; 16 Howmead, Berkeley, Gloucestershire GL13 9AS (GB).

(74) Agent: **WAITE, John**; Renishaw plc, Patent Dept., New Mills, Wotton-under-Edge, Gloucestershire GL12 8JR (GB).

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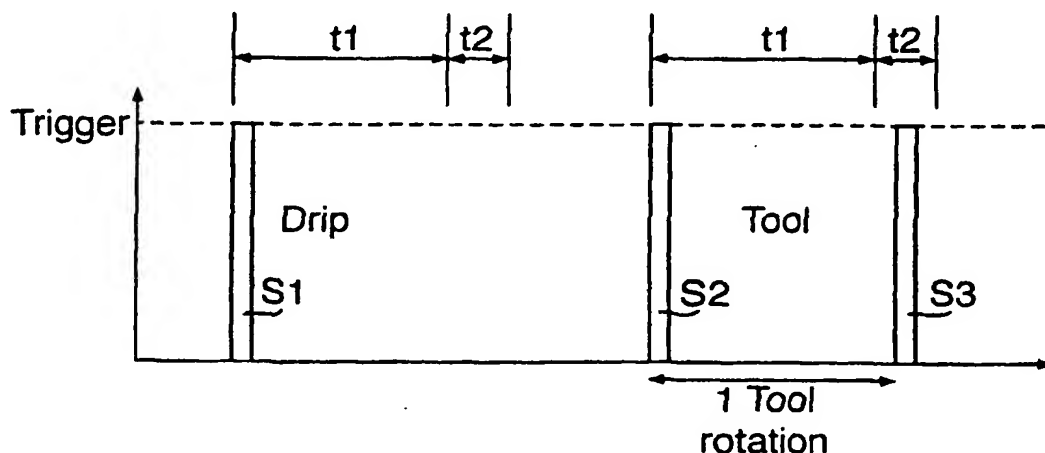
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(54) Title: OPTICAL MEASURING APPARATUS FOR MEASURING OBJECTS ON MACHINES



(57) Abstract: A light source generates a beam of light which is incident on a detector which generates a trigger signal when the beam incident upon it is occluded by a tool. To avoid trigger signals being produced when the beam is temporarily occluded by coolant drips passing through the beam, the detector produces a detection signal each time the beam is occluded, but only produces a trigger signal if a further detection signal is produced in a specified time interval from the generation of an earlier detection signal. One method of generating the time interval is by rotating the tool so that the beam is occluded at time intervals ( $t_1$ ) each time a cutting edge of the tool enters the beam. If no second signal is generated within an interval ( $t_2$ ) at the end of interval ( $t_1$ ) no trigger signal is produced.

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OPTICAL MEASURING APPARATUS FOR MEASURING OBJECTS ON  
MACHINES

5 The present invention relates to an optical measuring  
apparatus which enables a coordinate positioning  
machine (such as a machine tool) to determine the  
position of an object relative to a reference point.  
It may, for example, be employed on a machine tool for  
toolsetting operations.

10 A known tool setting device for use on a machine tool  
includes a light source which generates a fine beam of  
light which is incident upon a detector. During a  
toolsetting operation, the machine is operated to move  
15 the tool in a direction transverse to the direction of  
propagation of the light beam until a part of the tool  
interrupts passage of the light beam. Detection of  
this interruption is used to produce a trigger signal  
in the detecting unit, which is used by the machine to  
20 establish the relative position of its moving parts in  
order to determine dimensions of the tool. Such  
devices are known, for example, from German Patent Nos.  
DE 42 385 04 and DE 42 448 69, French Patent No.  
2,343,555, European Patent No. 98,930 and US Patent No.  
25 4,518,257. The devices may be used additionally for  
measuring the length or diameter of a tool to monitor  
tool breakage or wear.

The devices disclosed in the above-mentioned patent  
30 specifications use a narrow light beam into or through  
which the tool is passed. The detection units detect  
when the tool breaks into the beam from the resulting  
drop in the intensity of the light falling on them.  
The trigger signal may be produced as a result of a  
35 predetermined drop in the intensity of light falling on  
the detector as the tool enters the beam.

A problem which arises with such optical measuring apparatus is that coolant used on the machine can drip through the beam, or be thrown off the rotating tool  
5 into the beam, during the measuring operation and give rise to false trigger signals.

One method of overcoming this problem which is currently used, is to program the software in the  
10 machine controller to perform several measurements until a pre-selected number of measurements falling within a given tolerance have been obtained. The position of the tool is then assumed to be the average of these measurements. This method can give rise to an  
15 unacceptable increase in the measurement cycle time if a significant number of repeat measurements have to be taken.

The present invention seeks to alleviate this problem  
20 by providing a method of measurement which can differentiate between a genuine tool detection signal, and a signal produced by a coolant drip.

According to one aspect of the present invention there  
25 is provided a method of making measurements of an object on a machine tool using an optical measuring apparatus which includes a light source which generates a beam of light which is incident upon a detector, the method comprising the steps of:

30 generating a detection signal within the detector each time the beam is interrupted;  
evaluating the frequency and/or duration of the occurrences of said detection signals;  
emitting an output signal from the detector only  
35 if a further detection signal is also present within the detector in a specified time interval from the

generation of an earlier detection signal.

The timing of the detection signals can be achieved in various ways.

5

In one embodiment of the invention the tool is rotated, preferably, at a known specific speed. This gives rise to the generation of a regular sequence of said signals within the detector as the cutting edge (or edges) of the tool interrupt the beam. The generation of the first one of the said signals is used to initiate a timing sequence within the detector which sets a time interval ( $t_1$ ) substantially equal to the time taken for one revolution of the tool, followed by a second time interval ( $t_2$ ) which is substantially shorter than ( $t_1$ ). If it is the tool which has generated the signals in the detector then a second signal will be generated in the time interval ( $t_2$ ) as the cutting edge of the tool comes round again, and if this happens, the detector emits the output signal.

Alternatively, the generation of a detection signal within the detector can be used to start a clock which emits pulses of short duration synchronised with the speed of rotation of the tool. Again, if a second detection signal is generated within the detector during such a pulse then the detector emits an output signal. A number of clocks may be used which start sequentially as the detector generates its detection signals, and each of which stops if no second detection signal is generated within the detector during the next one of its pulses.

The invention also includes optical measuring apparatus for carrying out the method which comprises a light source for generating a light beam and a detector for

receiving said beam and which generates a signal when the beam is interrupted, wherein the detector includes a detection circuit which generates a detection signal each time the beam is interrupted, and signal  
5 processing means for evaluating the frequency and/or duration of the occurrences of said detection signals and which emits an output signal only if a second signal is generated by the detection circuit within a specified time interval after the occurrence of an  
10 earlier detection signal.

Examples of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

15 Fig 1 is a perspective view of an optical measuring apparatus incorporating the present invention;

Fig 2 is a representation of the output of the detector of Fig 1; and

20 Fig 3 is a block diagram representing the basic elements of the apparatus;

Fig 4 illustrates in lines 4a to 4f the signals generated in various parts of the signal processing circuit of the detector.

25 Referring now to Fig 1, the optical measuring apparatus is shown in a set up arranged to operate as a toolsetting apparatus, suitable for use, for example, on a machine tool. The apparatus includes a light  
30 emitting unit 10 which emits a beam 12 of light, and a light detecting unit 14, where the light beam 12 is detected. Power and signal control cables to the light emitting and detecting units 10,14 are routed via inlet ports 16, and both the units 10,14 are advantageously  
35 mounted, via pillars 18, on the base of the machine, either via an intermediate base 20, to which they are

both mounted, or directly to the base of the machine upon which they are to be employed.

In operation, the apparatus is used for toolsetting by operating the machine on which the apparatus is mounted to move the tool in a direction transverse to the direction in which the beam 12 is propagating. When a predetermined level of occlusion of the beam has been established, the detecting unit 14 emits a trigger signal which is used by the machine to determine the relative position of its relatively movable parts, thereby to enable dimensions of the tool to be determined.

Further mechanical and optical details of an example of such an apparatus are described in our European Patent Application No. 00303749.6 (which is hereby incorporated into this specification by reference) and are not therefore reproduced here.

Fig 2 shows the output of the detector in various circumstances. The detector output goes high (i.e. produces a detection signal) as shown by a voltage pulse when the beam is occluded to said predetermined extent. As can be seen by the first pulse S1 at the left-hand side of the drawing this can occur when a coolant drip passes through the beam.

In the first instance however, the coolant drip is a single occurrence, which produces a single short duration pulse.

When the edge of the rotating cutting tool breaks the beam there is also a short duration pulse S2, but this is followed by further pulses S3 (only one shown) as the same cutting edge comes into the beam again, or as other cutting edges of a multi-edged tool cut the beam

in turn.

In order to be able to identify the difference between occlusion of the beam by a drip, and occlusion of the beam by the edge of the cutting tool for the first time (which is the event which is required to be detected to measure the position of the cutting edge), the invention provides that a timer in the detector sets a first time interval  $t_1$  simultaneously with the detector generating its detection signal. In a specific embodiment ~~the time interval  $t_1$  is arranged to be equal~~ to the length of time it takes for one revolution of the tool. At the end of the time interval  $t_1$  the timer sets a shorter time interval  $t_2$ .

The detector monitors the time interval  $t_2$  for a second detection signal which is unlikely to occur if the first signal is a drip. This can be detected by either a high state of the output signal or a rising edge. If the second detection signal is present the detector issues a "skip" or trigger signal at the end of time interval  $t_2$ .

Since the time intervals  $t_1$  and  $t_2$  are accurately known the instant of the occurrence of the first rising edge of the detector output due to a cutting edge of the tool obscuring the beam can be calculated.

In order to calculate the timings, the speed of rotation of the machine spindle, and hence the cutting tool must be set. In order to keep the time for the measuring operation down a reasonable level, the spindle speed was set during experimentation at 1000rpm so that  $t_1$  was ostensibly 60ms. The interval  $t_2$  however, has to be large enough to cater for slight variations in spindle speed for example up to 5%, which

would cause a 3ms variation in  $t_1$ .

To centre the trigger signal in the time interval  $t_2$ ,  $t_2$  is set at  $t_1 + \frac{1}{2}t$  which must be equal to 60ms. Thus  $t_1$  was actually set at 58.5ms.

It is not necessary for the speed of rotation of the tool to be known prior to measurements being taken since it can be measured by timing the distance between the rising edges of the first two consecutive pulses out of the sequence of pulses generated by the detector. The time interval ( $t_1$ ) can then be set between the second and third rising edges and ( $t_2$ ) can be timed from the third rising edge.

The basic elements of the apparatus of the invention are shown in block diagram form in Fig 3. The light beam 12 from the transmitter 10 entering the detector 14 impinges on a photodetector in a detection circuit 72 which produces the signals when the beam is interrupted. Signals generated in the detection circuit 72 are passed to a signal processor 74 which includes the necessary timing devices for signal analysis. The detector output signals are passed directly to the machine controller 80 which stops the machine, and evaluates the machine scale readings to determine the position of the machine.

Fig 4 illustrates an alternative embodiment in which one or more clocks in the detector are used, each of which generates a series of pulses initiated by the detector issuing a signal to indicate that the beam has been interrupted;

Fig 4a shows an example of a series of events created by a mixture of teeth and drips interrupting the beam;



Fig 4b shows the signals created by these events converted to pulses at the output of a comparator in the signal processor of the detector;

Fig 4c shows the situation which occurs in the  
5 detector when a single clock is used;

Fig 4d shows the situation which occurs in the detector when a second clock is used;

Figs 4e and 4f respectively show the results of combining the comparator output with the outputs of  
10 clock 1 and clock 2.

It can be seen from Fig 4a that the drips occur and interrupt the beam at random intervals while the beam interruptions caused by the edge of the tool occur at  
15 regular intervals. Each beam interruption is labelled as a numbered event E.

Fig 4b shows the comparator output pulses corresponding to the events.  
20

Fig 4c shows that the first clock starts when event E1 occurs but because there is no event occurring when the second clock pulse is sent to the signal processor the clock is stopped. The clock is started again on the  
25 occurrence of event E3 which is also a drip, but again because its second pulse occurs between events E4 and E5 it will not see event E4 and will stop. The situation is the same when it starts again at event E5. Only when it starts again at event E7 will its pulses  
30 be synchronised with the occurrences of the cutting edge of the tool interrupting the beam at event E9 and beyond so that a trigger signal will be produced on event E7. This signal will have missed the first occurrence of the cutting edge interrupting the beam at  
35 E6 and will produce an erroneous reading.

With the embodiment which uses two clocks however, as shown in Fig 4d, the second clock will be started on event E6 because at that time the first clock is running. Since event E6 is an interruption of the beam  
5 by an edge of the cutting tool there will be a further event E7 occurring when the clock pulse is generated. The signal processor will recognise that the clock pulses and the events have now become synchronised and will generate a trigger signal on the rising edge of  
10 the pulse. Since the generation of the clock pulses and the beam interruptions are synchronised, the time at which the first beam interruption occurred can easily be determined.

15 The situation is less complex if the first event is caused by a cutting edge of the tool, because the first clock will start and will see a synchronised event during its first pulse and cause a trigger signal at that time.

20

If a drip occurs between the first and second events this will be ignored by the first clock since it will not occur during its first pulse. Hence the drip will not affect the generation of the trigger signal under  
25 these circumstances.

Although the invention has been described using one or two clocks, other benefits may be achieved if more clocks were used which are set at different  
30 frequencies.

For example, the apparatus could be used at different speeds of spindle rotation without having to re-set the timing of the existing clocks, and additional clocks  
35 would allow the apparatus to deal with an atmosphere where a lot of drips could be expected. The number of

clocks used would be a trade-off between the benefits to be obtained, and the expense of the additional signal processing capability required.

5 The invention can also be used when the tool is not rotating to measure tool length or diameter during tool setting, or for tool breakage detection. In such an embodiment the tool is moved at right angles to the beam until its tip or flank interrupts the beam. The  
10 signal produced by the detector is used to start a clock in the signal processor which evaluates the detector output after a time  $t$ . If the detector output is still high at that time, denoting a signal is still present, the signal processor produces a trigger  
15 signal.

In yet another embodiment, the signal processor may incorporate a device which identifies synchronous events. The inputs to the device are samples at  
20 regular intervals and the samples are stored in a buffer of fixed length, the new contents constantly overriding the old. The buffer can be implemented using a shift register which monitors the detector output and writes its current state into the shift  
25 register each time a sample is taken. If the buffer is split across two bytes, testing for repetitive patterns can be achieved by comparing the two halves. For example, if the sample rate is eight times the speed of rotation of the tool and the result of each sample is  
30 shifted through two eight bit registers, when a first signal occurs this shows up as a high (1) in the first cell of the register. The sample moves through the register until it is passed into the first cell on the second half. If there has been no synchronous event  
35 the sample passes through the register to the end.

If however, another high sample is received in the first cell of the first half of the register just as the first sample moves into the first cell of the second half of the register then the two halves will  
5 become identical once again and a trigger signal will be issued.

The invention has been described with reference to the elimination of spurious trigger signals in an optical  
10 measuring apparatus on a machine tool, but may have wider application using other forms of optical measuring apparatus on other types of machine. The scope of the invention is therefore, to be taken as that defined by the appended claims.

## CLAIMS

1. A method of making measurements of an object on a machine using an optical measuring apparatus which  
5 includes a light source which generates a beam of light which is incident upon a detector, the method comprising the steps of:  
generating a detection signal within the detector each time the beam is interrupted;  
10 evaluating the frequency and/or duration of the occurrences of said detection signals;  
emitting an output signal from the detector only if a further detection signal is present within the detector in a specified time interval from the  
15 generation of an earlier detection signal.
2. A method according to claim 1 and comprising the further steps of:  
rotating the object;  
20 generating a first time interval ( $t_1$ ) which is dependent on the speed of rotation of the object; and  
generating the specified time interval as a time interval ( $t_2$ ) which is shorter than ( $t_1$ ) and commences at the end of the interval ( $t_1$ ).
- 25 3. A method according to claim 2 wherein the object is a tool on a machine tool and the tool is rotated at a known specific speed and the time interval ( $t_1$ ) is substantially equal to the time taken for one  
30 revolution of the tool.
4. A method according to claim 3 wherein the apparatus further includes a clock, the method comprising the further steps of:  
35 rotating the tool;  
causing the clock to initiate the emission of a

series of pulses of short duration which are synchronised with the speed of rotation of the tool, the first pulse being emitted to coincide with a detection signal being generated in the detector;

- 5 emitting an output signal from the detector only if a detection signal is also present within the detector during the existence of a clock pulse;  
stopping the clock if no such detection signal is present in the detector.

10

5. A method according to claim 4 wherein a clock pulse is produced for each revolution of the tool, and an output signal is emitted from the detector only if a detection signal is present with the detector during  
15 the next pulse emitted by the clock following said first pulse.

6. A method according to claim 4 wherein the apparatus includes two clocks the method comprising the  
20 further steps of:

causing a first clock to initiate the emission of a first series of said pulses when a detection signal is generated within the detector;

- causing the second clock to initiate the emission  
25 of a second series of said pulses commencing with the generation of a further detection signal within the detector in the interval between two successive pulses of the first clock; and

- emitting an output signal from the detector if a  
30 detection signal is also present within the detector during the existence of the next pulse in the second series if the detector has not emitted an output signal based on the first series of pulses.

- 35 7. A method according to claim 6 wherein the apparatus includes additional clocks, the method

comprising the steps of sequentially initiating the emission of respective series of said pulses if a detection signal is generated within the detector and all of the previously started clocks are running.

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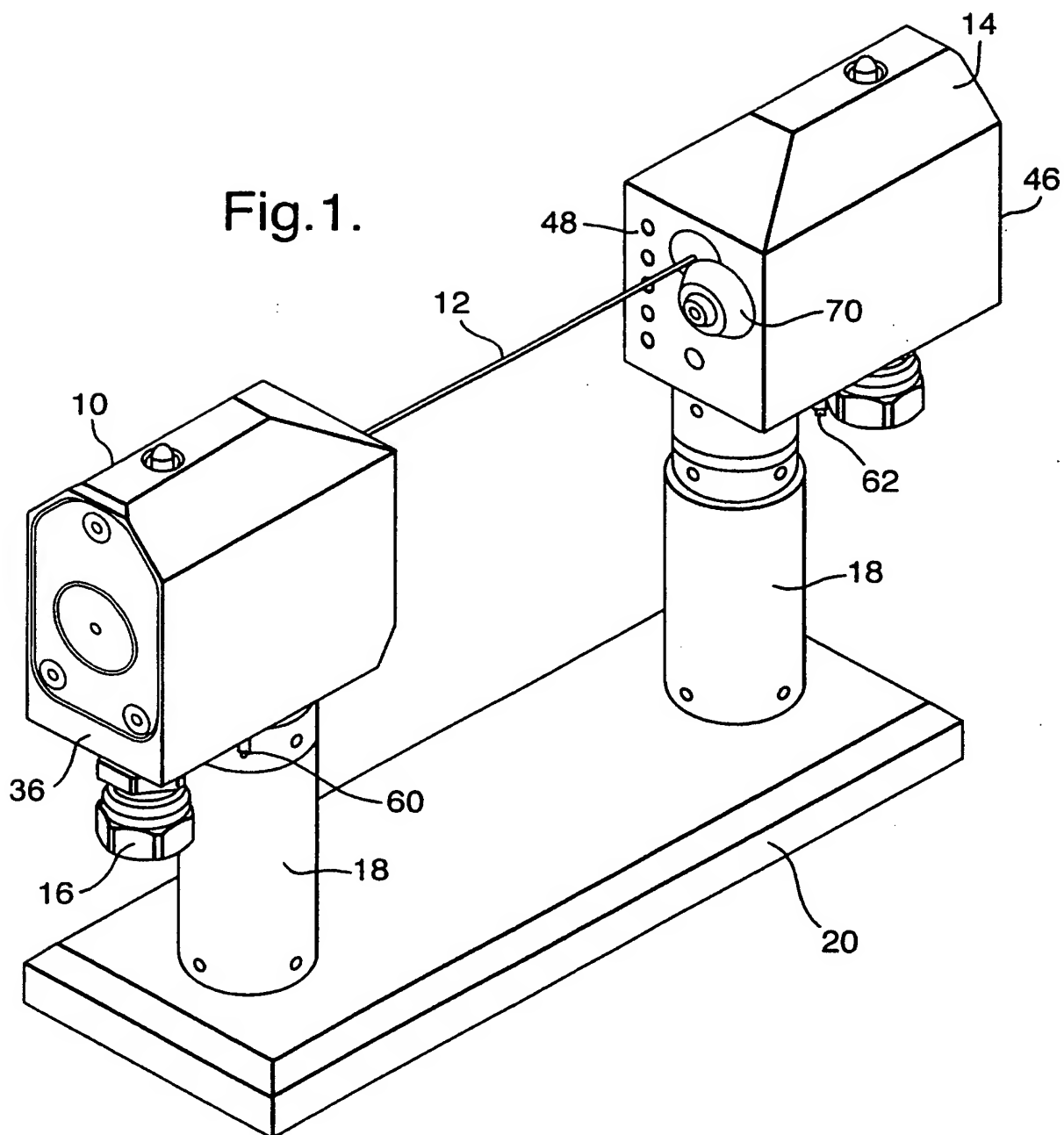
8. A method according to claim 6 wherein the apparatus includes additional clocks, the method comprising the steps of setting the clocks to produce respective series' of pulses at different frequencies set to coincide with different speeds of rotation of the tool, and causing the initiation of the emission of a said series of pulses appropriate to the speed of rotation of the tool.

15 9. Optical apparatus for measuring objects on machines comprising a light source for generating a light beam and a detector for receiving said beam and which generates a signal when the beam is interrupted, wherein the detector includes a detection circuit which  
20 generates a signal each time the beam is interrupted, and signal processing means for evaluating the frequency and/or duration of the occurrences of said signals and which emits an output signal only if a  
25 second signal is generated by the detection circuit within a specified time interval after the occurrence of said signal.

10. Optical measuring apparatus according to claim 9 and wherein the object is a tool on a machine tool.  
30

35

Fig.1.





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Fig.2.

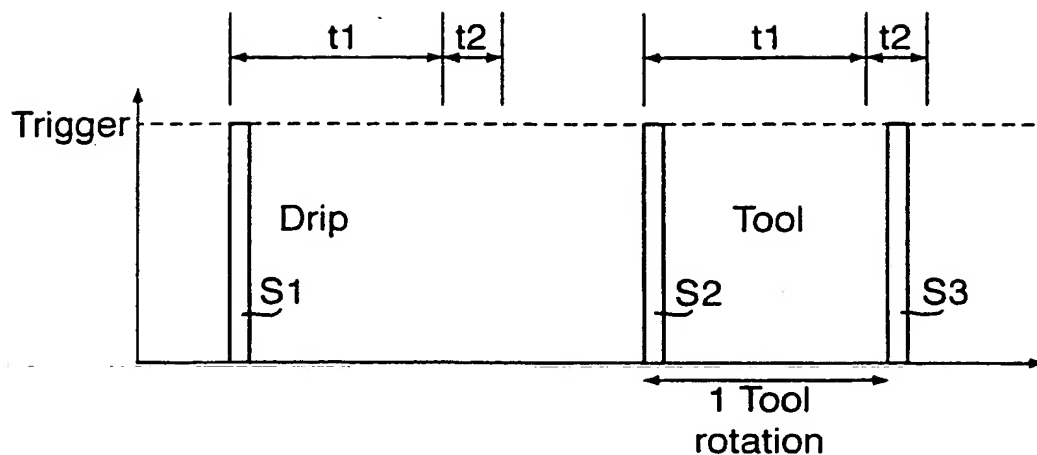


Fig.3.

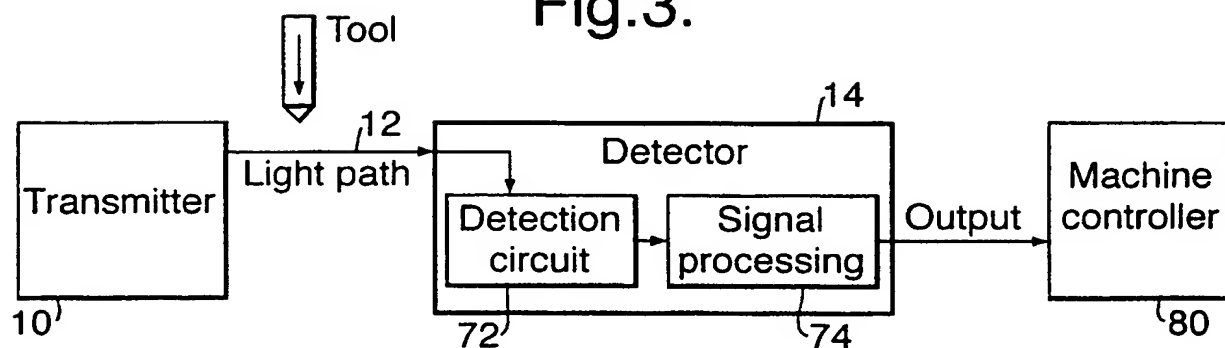
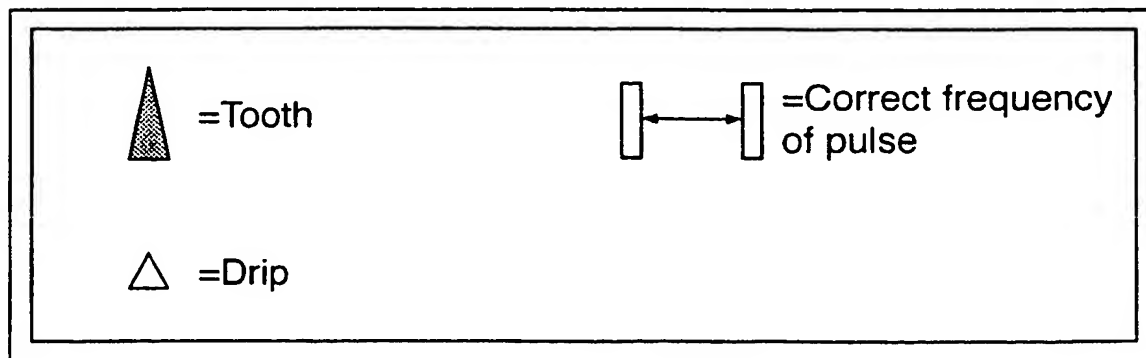
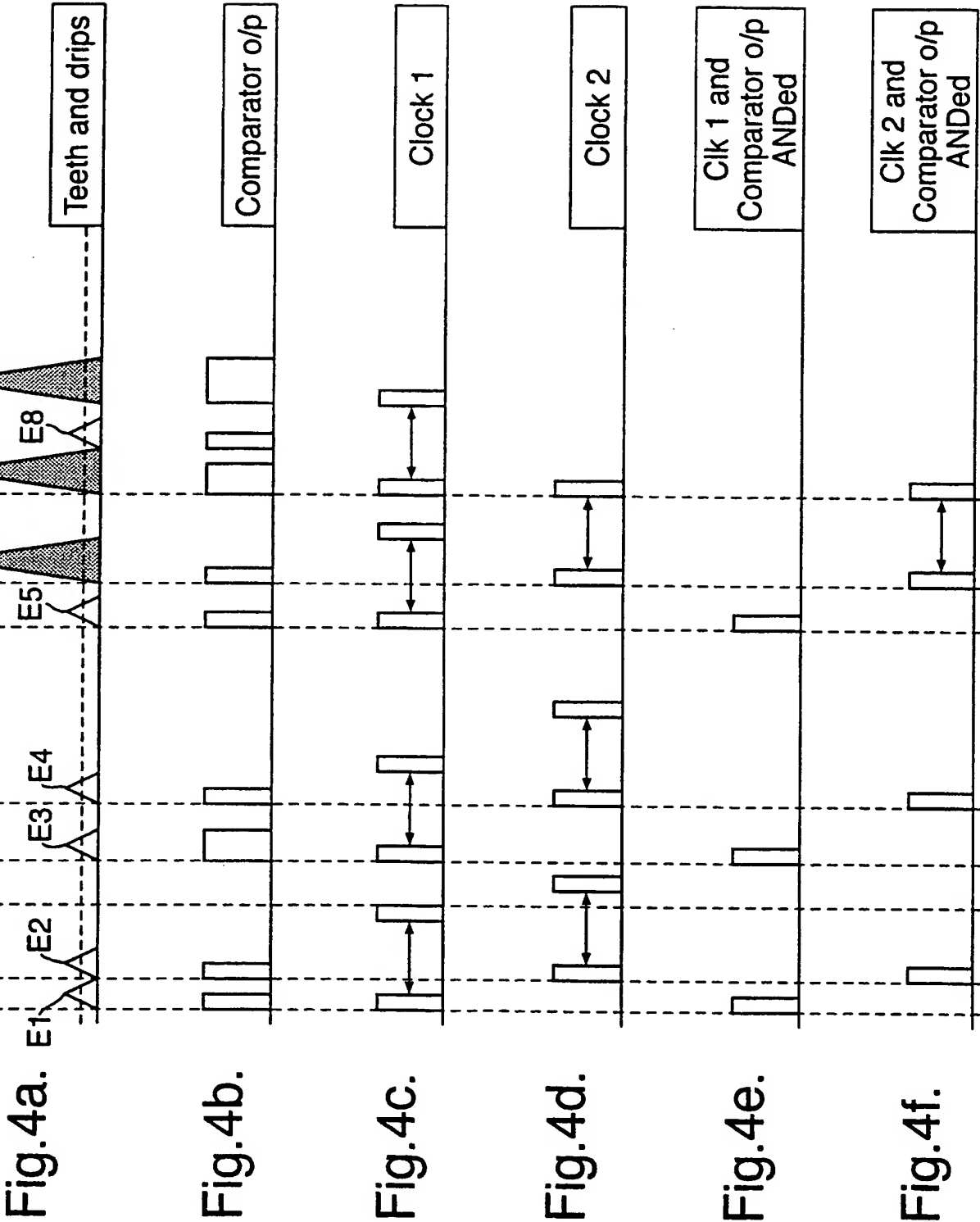


Fig.4.





# INTERNATIONAL SEARCH REPORT

I. International Application No  
PCT/GB 00/04403

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 G01B11/00 H03K17/94 G01V8/10 B23Q17/24 B23B49/00

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 G01B H03K G01V B23Q B23B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

WPI Data, EPO-Internal, PAJ

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

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A	DE 43 23 910 A (LEUZE ELECTRONIC GMBH & CO) 19 January 1995 (1995-01-19) abstract; figure 3 ---	1
	-/--	

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2  
NL - 2280 HV Rijswijk  
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,  
Fax (+31-70) 340-3016

Authorized officer

Westhues, T

# INTERNATIONAL SEARCH REPORT

International Application No  
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## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Information on patent family members

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